

CENTRAL NERVOUS, CARDIOVASCULAR AND VISUOMOTOR STUDIES
RELATING TO SPATIAL ORIENTATION IN A 30-DAY PRIMATE FLIGHT

W. R. Adey

Space Biology Laboratory, Brain Research Institute, University
of California, Los Angeles

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1. Introduction

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Spatial orientation on the basis of environmental cues has evolved in the mammalian organism to a sensitive and powerful integrative mechanism, dependent on simultaneous or sequential inputs in many sensory modalities. Visual, auditory, vestibular, somatic and even olfactory cues all play important roles in information transacted in the subtle and continuous processes that relate the subject to a multi-dimensional environment. An essential parameter in this sensory integration, and one frequently overlooked, is the factor of timing, whether this be in such phenomena as the saccadic scanning of a visual field, or in multi-sensory barrages entering the nervous system in different modalities, and their subsequent temporal interplay in higher nervous structures. At an even more fundamental level, the coding of information in both slow waves and pulse-coded activity in cerebral tissue demands consideration of the vital role of spatio-temporal patterning in the transmission and transaction of information within the brain. Very truly, then, temporal coding is the essential link between windows on the world without provided through sensory transducers, and windows on the world within through which we may peer, often "as through a glass darkly," in sensing electro-physiological signals.

The cerebral cortex, in its interrelations with subcortical structure may be likened to a screen on which the images of sensory experiences are cast in a **transactional** sense. It is also probably the site of their storage in terms of **permanent** physico-chemical changes in a "memory trace," with retrieval or recall dependent on reestablishment of electrical patterns in corticosubcortical circuits resembling those associated with the initial deposition of information.

Here, the interplay of limbic structures of the temporal lobe with midbrain and subthalamic structures, and with the establishment thereby of requisite patterns of activity in corticosubcortical systems, is of vital importance. Spatial orientation draws heavily on such mechanisms, which are amenable in great degree to direct electrophysiological monitoring (Adey, 1965, 1966).

Specifically, integrity of the parieto-occipital cortex of the primate brain is essential to normal spatial orientation. The parietal lobe syndrome in man following damage to this region in the dominant hemisphere attests to its importance (Critchley, 1953). It is characterized by severe impairment of navigation in previously familiar environments, and equally, by neglect of the contralateral half of the body in its normal participation in somatic and motor functions.

Yet, there is clear evidence that, in the hierarchical organization of cerebral structures, the focusing of attention to achieve spatial orientation, and the psychological processes of discrimination and judgment, require integrity of mechanisms relating hippocampal regions of the temporal lobe with subcortical structures. Participation by these systems in orientation and discrimination has been extensively investigated (Grastyan, Lissak, Madarasz and Donhoffer, 1960; Adey, Dunlop and Hendrix, 1960; Adey, Walter and Lindsley, 1962; Adey & Walter, 1963; Radulovacki and Adey, 1965). In particular, it would appear that the isolated pursuit of vestibular functions, without regard to higher levels of neural integration in orienting mechanisms, may disregard quite fundamental aspects of these integrative processes in relation to space flight.

Evaluation of novel environmental stimuli, and their precise spatial localization involves an essentially specific physiological response, the orienting reflex, first described by Pavlov (Sokolov, 1963; Vinogradova, 1961). Its essential components involve turning of head and eyes towards the novel stimuli, (Konorski, 1943) and the selective extinction of separate components of the stimulus complex

with repeated presentations. Sokolov has proposed an inverse relationship between the strength of orienting responses and the level of conditioning, from his studies of visual task performance in man. Evaluation of processes of spatial orientation must thus necessarily consider questions of perception, recent memory, learning and recall (Drachman and Ommaya, 1964; Adey, 1966).

In framing our flight experiment P-1001 in Biosatellite D of the Biosatellite Program of OSSA, we have attempted to encompass a gamut from direct assessment of vestibular functions in perception, to higher nervous functions in sleep and wakefulness, and in perception, recent memory and visual discriminative performance. These central nervous studies have been combined with peripheral measures, including electrooculograms, electromyograms and galvanic skin responses. We have closely coordinated these baseline investigations with proposed cardiovascular monitoring by our co-investigator, Dr. J. P. Meehan of the Department of Physiology, University of Southern California, and with catheterization procedures and urinary analyses by Dr. A. T. K. Cockett, of the Harbor General Hospital. In-flight urine analysis will be undertaken by Dr. N. Pace, of the Department of Physiology, University of California, Berkeley, and by Dr. J. Rho, Jet Propulsion Laboratories. Calcium balance studies will be performed by Dr. P. Mack, Texas Christian Medical Women's College. The test animal will be a Macaca nemestrina (pig-tail macaque) monkey, weighing 15 pounds (6.8 Kg) at launch.

2. Experimental Design

a. Central nervous monitoring and implantation procedures

Implantation procedures have been described elsewhere (Adey, 1964), including details of histological controls on damage arising in brain movement relative to the electrodes (Adey, Kado, Winters and de Lucchi, 1963). Bipolar electrodes formed of pairs of 29 gauge stainless steel tubing, insulated except at the tips, and separated by 2.0 mm have been stereotaxically

inserted into selected deep brain structures (Fig. 1). Surface records are obtained from stainless steel screws in the calvarium, and additional screws are used to secure the mass of acrylic covering the skull and enclosing connecting plugs.

It is planned to record ten channels of EEG data. These leads have been selected, on the basis of our extensive studies in monkeys, chimpanzees and man (Reite, Rhodes, Brown and Adey, 1965; Rhodes, Brown, Walter and Adey, 1965; Adey, Rhodes and Kado, 1963; Walter and Adey, 1965), as reflecting most sensitively changing states of consciousness, including broad shifts in the range from emotional arousal and alerted behavior, through drowsiness and fatigue, to actual sleep. They also specify appropriately the various stages of sleep, including dream states. In finer computational analysis, as described below, distinctive patterns can be reliably detected across decision making states, ranging from simple vigilance tasks to difficult visual discriminations based on a one-second visual task exposure (Walter, Rhodes, Brown and Adey, 1966). These leads are taken from the amygdaloid and hippocampal regions of the temporal lobe, from the midbrain reticular formation, and from surface leads overlying frontal, central, parietal and occipital cortex.

b. Electro-oculographic and electromyographic recording

Assessment of orienting responses places particular significance on monitoring head, eye and trunk movements. Satisfactory long-term recording from electrodes implanted in soft tissues requires that they be resistant to shearing stresses imposed by movement in tissue planes. When implanted in muscles, they should not devitalize these structures to the point of inducing scar formation and loss of electromyographic activity.

A satisfactory solution to the shearing problem appears to have been found in the use of stranded stainless steel wire, composed of 7 strands of 44 gauge wire, and insulated with silicon rubber. The bared terminal 1-2 cm

of the wire has been loosely sutured through the muscles, and then threaded subcutaneously to the scalp where they are attached to the cranial plugs.

For electromyographic (EMG) recording in the neck, pairs of leads have been placed in adjacent portions of the splenius capitus and trapezius muscles. Similar leads in posterior and lateral trunk muscles have performed satisfactorily over periods of several months. Loss of tone in cervical musculature has been found a consistent accompaniment of dream sleep states in animals and man (Jacobson et al, 1965), so that it will be important to assess any changes which may occur in tonic activity in cervical musculature in both waking and sleeping states during prolonged weightlessness.

Electro-oculographic leads are inserted through small holes drilled in the upper and outer margins of the bony orbit. EOG data will be valuable in monitoring eye movements during orienting responses and alerted behavior, as well as in the large and rapid movements of dream sleep.

c. Monitors of autonomic responses; galvanic skin response, impedance pneumogram, and electrocardiogram.

Classic sensing techniques for galvanic skin responses (GSR) are not usually required to provide data for more than a few hours, so that special techniques were developed to record reliably for periods in excess of 30 days. A 2 cycles per second square wave, with an amplitude of a few millivolts, and applied to electrodes 1 cm square on the sole of the monkey's foot has been found a reliable method for periods in excess of 30 days, with undiminished responses to alerting stimuli, and in various sleep states, even after prolonged application.

The impedance pneumogram (ZPG) is attached to sensors in left and right midaxillary lines, and uses a carrier frequency of 50 Kcs per second with an amplitude of 1 mV. This signal is compatible with the EEG signal conditioners, producing negligible interference in EEG records.

Electrocardiographic (EKG) records are secured from the same electrodes used for the impedance pneumogram. The location of these leads in the axillae differs from classical placements for precordial recording, etc., but qualitative information on ectopic beats and bundle conduction characteristics is readily available.

d. Monitoring of cardiovascular functions.

These investigations are under the direction of Dr. J. P. Meehan, of the Department of Physiology, University of Southern California. Dr. Meehan's experience in the instrumentation of two chimpanzee space flights (by Ham and Enos) has provided an incomparable background in the design and performance of such experiments. Pressures will be recorded directly in femoral and carotid arteries, in the right atrium and left ventricle, by catheters connected to a total of six strain gauge transducers.

Much baseline data has been collected by Dr. Meehan in proving feasibility for a 30-day flight. Small impulse pumps, operating from a capacitor discharge power source, inject approximately 0.003 ml of heparin solution into each catheter once each minute (Fig. 2). Such small amounts are adequate to ensure patency of the catheters, so that 1500 ml. of solution provides an adequate reservoir for preflight preparations and flight requirements for all six catheters.

Catheterization for such extended periods requires meticulous asepsis in initial surgery and in all subsequent manipulations if infection is to be avoided. Additional prophylaxis has been provided by crystalline penicillin (1.0 μ g/ml.) in the heparin solution, and two subcutaneous depots of penicillin (4.0 ml, 2.4 million units each) in slowly absorbed form injected into subscapular regions. No. clinical infection has occurred in catheterizations up to 50 days.

e. Urine and feces collection; in-flight urine analysis.

As has been emphasized in relation to extended manned space flight, successful waste management ranks as a critical requirement. Moreover, urine and feces analysis provide vital information on whole body composition, against which changes in such functions as spatial orientation, discriminative performance and biological rhythmicity must be equated if a realistic appraisal of performance capability is to be made.

Extensive investigations by our colleague, Dr. A. T. K. Cockett, of the Harbor General Hospital, Los Angeles, have resulted in a technique of perineal urethrostomy which allows ready catheterization of the bladder, and an essentially watertight system of urine collection. Dr. Cockett has performed extensive steroid analyses on urine so collected during couch-restraint similar to that required for the flight animal.

Insufficient spacecraft power has prevented implementation of our plans to recover daily urinic samples that would be fractionated and then frozen or lyophilized in flight. Other developments, however, may nevertheless make it possible to perform certain in-flight urine analyses by fluorescence microscopy. Dr. Pace, of the Department of Physiology, University of California, Berkeley, and Dr. J. Rho, of Jet Propulsion Laboratory, Pasadena, have investigated the feasibility of measuring concentration of calcium, urea, creatine and creatinine in urine sampled en route to storage in the adapter section of the vehicle. The readings will be telemetered every 6 hours.

Feces collection in the weightless state presents special problems. Our laboratory has evolved a technique, which, in terrestrial testing, appears to ensure reliable transfer to a collector-can behind the couch. An accurately moulded soft rubber pad is backed by a rigid plate, which is screwed to the ischial tuberosities. A flexible hose connects this plate with the collector, and is flushed with a disinfectant spray and air, injected perianally.

On recovery of the spacecraft, the calcium content of the feces will be analyzed by Dr. P. Mack, of the Texas Christian Women's Medical College, as part of her study of depletion of skeletal calcium in weightlessness, by wedge densitometry of the skeleton pre- and post-flight. Dr. Mack has already made extensive baseline studies of the monkey skeleton by this method.

f. Behavioral tasks, including visual orientation; food reinforcement and feeding techniques.

While it has been contended that investigation of weightlessness demands study of subjects in whom it is the only imposed variable, contamination of such an impressively simple situation in a primate experiment can be justified on the basis that the very perturbations introduced by tests such as partial feeding by task performance on a scheduled basis, afford an opportunity to observe effects of a combination of variables on performance ability. Weightlessness then becomes the only variable not forming part of terrestrial baselines, and the paradigm then emphasizes the value of adequate preflight simulations.

We have included two tasks in this experiment. They will be scheduled successively both early and late in the 12-hour "day" imposed in the flight schedule. The first involves a delayed matching-to-sample test, and the second is an eye-hand coordination task.

In the first task, a symbol appears for 5 seconds in the center of a rectangular matrix, and is then extinguished (Fig. 3). After a delay of 20 seconds, the whole matrix is illuminated for 10 seconds. The original symbol now appears embedded in the total matrix in a different location from that in which it was originally displayed. When it is touched by the animal, a food pellet reward is offered. Our experience indicates that this is an exacting task in recent memory and perception for the pig-tail macaque, and attainment of a high performance level takes approximately two months of

daily training.

The second task tests coordination of eye and hand in a manner directly related to spatial orientation. Two co-rotating discs surround the periphery of the matrix board described above. A small window in the front disc allows access to the rear disc, on which is mounted a small red button switch (Figs. 3 and 4). The discs rotate at different rates, so that the position of coincidence of window and button in successive encounters are constantly shifting in space. Our early experience indicated a surprising facility on the part of the monkey in performing this task, as well as a considerable motivation to succeed. Speeds of rotation were constantly increased to keep pace with increasing proficiency. It appears that the monkey can perform at over 80 per cent correct with a window-disc rotation speed of 85 r.p.m., and a coincidence time for window and button of the order of a fifth of a second. To accomplish its goal, the animal has its head moving through a circular pattern approximately the speed of rotation of the disc. This phenomenon alone suggests that vestibular disturbances associated with the rapid head movement in weightlessness may profoundly disrupt the performance, if frequent reports by astronauts and cosmonauts of disability in similar rapid movements provide a basis for comparison.

Feeding is by pellets dispensed from a feeder modified from a chimpanzee feeder, originally developed at Holloman Air Force Base for the Air Force Office of Scientific Research (Fig. 5). This device carries 225 pellets on each of 8 tapes, to which the pellets are adherent. Each tape is carried on a drum, and all drums are mounted on a single shaft. Pellets from each tape are dispensed separately and successively through a row of windows. Each pellet measures 2.0 cm by 2.0 cm by 5.0 mm, and has an energy value of 7.5 Kcal. The animal may 'win' 40 pellets per day by correct task performance. At the close of the 'day', it may gain the remainder of a daily ration of

60 pellets on an ad libitum basis. To avoid hoarding, however, if more than two pellets remain unclaimed in the feeder windows, the feeder is disarmed until they are removed. Flavoring has been tested on the basis of continued attractiveness in the absence of other food.

Drinking water is provided from the General Electric Company hydrogen-oxygen fuel cell, which powers the spacecraft. After filtration, the water is delivered to a nipple adjacent to the animal's mouth (Fig. 6). Water rationing is at the rate of 30 ml per hour during the 12-hour "day," and at one-third that rate during the "night," giving 540 ml per 24 hours. If telemetered data indicates dehydration, a ground command maintains "night" watering at the "day" rate, allowing 720 ml per 24 hours.

3. Simulation of Flight Conditions Relating to Spatial Orientation; Effects of Acceleration and Vibration

In the context of this meeting, special significance attaches to those simulations testing vestibular functions and spatial orientation. Many of these studies have been reported elsewhere (Adey, Kado, Winters and de Lucchi, 1963; Adey, 1965; Adey, Kado and Walter, 1966).

a. Effects of simple and compound linear accelerations.

Transverse acceleration to 5G (+Gy and -Gy) have little effect on this monkey's ability to perform an oddity discrimination task resembling the matching-to-sample task described here for the flight experiment.

The Thor-Delta acceleration profile for this flight imposes a peak transverse acceleration in the first stage firing of 12G with the animal in the "eyeballs in" position (+Gy). In its initial formulation, the final injection into orbit required a vehicular spin to 100 r.p.m. for 100 seconds, but this requirement has since been deleted. Simulations of this original flight profile revealed interesting EEG differences between simple centrifugal

acceleration and compound acceleration in two planes. Evidence was also found of continuing changes in EEG and EKG patterns after the high G pulse imposed by the simulated booster first stage firing (Fig. 7).

The effects in the visual cortex (Fig. 7C) of the initial 12G acceleration were minor, with a small peak in energy in middle frequency bands from 6 to 25 cycles per second as the acceleration reached its peak and suddenly declined. No significant peaks occurred in the low G loading of the second stage. With stopping of the centrifuge (indicated by the 1G vertical line), however, there was a rapid increase in energy levels between 6 and 13 cycles per second, persisting for most of the coasting phase. Commencement of the final orbital injection phase, with 5G of transverse acceleration and concomitant 100 r.p.m. spin evoked a quite different pattern of energy distribution from simple acceleration. Marked energy peaks occurred in the low frequency bands from 3 to 8 cycles per second. Energy distribution rapidly resumed the characteristics of control records at the end of the injection phase.

The amygdala (Fig. 7D) showed similar changes. A moderate increase in energy in the low frequency bands from 3 to 8 cycles per second occurred in the "coasting" phase, with a cyclic periodicity in peaks of 30 to 50 seconds. Evidence of this periodic peaking was detectable at higher frequencies but diminished progressively in the range from 13 to 45 cycles per second.

In the hippocampus, (Fig. 7B) no significant changes in spectral content accompanied either initial or terminal phases of the boost simulation, although the energy levels in the coast phase rose moderately, and exhibited the cyclic changes described in the amygdala.

In summary, it would appear that changes lasting through the coasting phase may have been induced by the preceding high G pulse in the first stage of booster acceleration, and may relate to cardiovascular readjustments and concomitant changes in cerebral oxygen tension occurring with such a pulse,

as described by Kovalenko, Popkov and Chernyakov (1963).

Interrelations were noted between cardiac irregularity and paroxysmal slow wave activity following high G loading. In the simulated booster profile, the pulse slowed as the acceleration approached the initial 12G peak (Fig. 7C). During the following coasting phase, paroxysms of high amplitude EEG slow waves appeared in many areas, including visual cortex, amygdala, hippocampus and midbrain reticular formation (Fig. 8D). Between these epochs the heart was regular, but missed beats appeared consistently during the paroxysms (Adey, Kado and Walter, 1965). No comparable abnormalities occurred after combined centrifuging and spinning at around 5G (Fig. 8E), and they may relate to readjustment in cerebral vascular mechanisms, since they always followed onset of the cerebral dysrhythmia.

b. Characteristics of cortical and subcortical EEG records during whole body vibration; effects of bilateral eighth nerve section on vibration-induced EEG driving.

Results presented elsewhere have indicated the presence of a "driving" in EEG records from cortical and subcortical structures during whole body vibration, at certain frequencies in the test spectrum of 5 to 40 cycles per second, using 0.25 inch (6.2 mm) double amplitude between 5 and 13 cycles per second, and 2G peak-to-peak in the range from 13 to 40 cycles per second. (Adey, Kado, Winters and de Lucchi, 1963).

More recent studies with extensive computer analyses (Adey, Kado and Walter, 1965) have confirmed earlier indications that this induced EEG rhythmicity has the characteristics of a physiological "driving," and that it appears distinguishable from superficially similar phenomena of artifactual origin in connecting cables or loose plug connections. Autospectral density plots showed little or no evidence of EEG driving below 9 cycles per second,

despite powerful head movements. Driving at the shaking rate was frequency selective and maximal in the range 10 to 15 cycles per second. However, in many instances, maximum EEG energy peaks occurred at other than shaking frequencies, and without harmonic relationship to shaking frequencies (Fig. 9).

Calculations of coherence (Walter, 1963), or linear predictability, were high between cortical and subcortical leads at EEG frequencies unrelated to concurrent shaking frequencies, and absent from baseline records before or after shaking (Fig. 10). This may imply aspects of cerebral system organization with ephemeral sharing of activity elicited by the vibratory volleys.

Coherence between head or table accelerometers and cortical and subcortical leads were below significant levels at fundamental driving frequencies below 11 cycles per second, although significant coherence peaks appeared at other EEG frequencies. Shaking in the range 11 to 17 cycles per second produced many coherent relationships at fundamental driving frequencies, and at harmonically related and unrelated EEG frequencies.

After bilateral eighth nerve section, there appeared to be an increased susceptibility to driving during vibration (at 11 to 13 cycles per second) in midbrain reticular formation and nucleus centrum medianum, which showed a wide range of coherent frequencies with the table accelerometer (Fig. 11). This possible increase in their driving may relate to their close relations to somatic sensory pathways. Certainly, the driving was not abolished by eighth nerve section, although it was abolished or greatly reduced by anesthesia and death. Its frequency selective characteristics suggest a physiological origin, and underlying mechanisms have been discussed elsewhere, including the role of abdominal, thoracic and cervical tissues (Adey, Kado and Walter, 1965). Disruption of behavioral performance occurred at frequencies inducing EEG driving, with little or no behavioral effect at lower frequencies of vibration that also produced violent head movements (Adey, Kado, Winters and de Lucchi, 1963).

4. Development of the Biosatellite Capsule for 30-Day Primate Flight

The various systems necessary for this experiment have now reached a stage of development where system tests of substantial portions of the experiment are possible.

The couch support for the monkey is located centrally in the capsule, with the animal facing forward in the vehicle, with lower limbs flexed at hip and knee. An effective suit-restraint has been developed by Wright-Patterson Air Force Base, and provides for the animal to ride on a fabric sling to which the suit itself is attached with zipp-fasteners. A torso harness assists in restraining the shoulder girdle against the couch. The animal's legs are contained in fabric sleeves and covered with a restraining apron (Figs. 12 and 13).

On the animal's right are the pellet feeder and watering device. Positioned in front of him is the behavioral test panel, at about waist level. To his left, it is proposed to install a camera. Behind the couch are the feces collecting can, and at a higher level, the pumps for the cardiovascular sensors and associated signal conditioners. Also behind the couch will be the signal conditioner package for the EEG, EKG, EOG, EMG and ZPG channels. The flight animal will be placed in the vehicle a few hours before launch, and the capsule sealed by attachment of the front hatch and heat shield. This cover will also contain batteries and tape recording equipment.

Much effort has gone into the development of a mixed gas (oxygen-nitrogen) life support system at one atmosphere. Such a system has not been previously used in U. S. animal or manned flight. Cabin temperature should be maintained within a narrow range around 70°F (21°C).

5. Data Acquisition and Analysis.

The overwhelming quantity of data gathered in such an experiment requires early and earnest consideration in planning efficient data reduction and automated analysis. The techniques developed in our laboratory for handling massive amounts of neurophysiological data (Adey, 1965), and more recently, in application of pattern recognition techniques to the initial computed outputs, lend themselves to treatment of both neurophysiological data gathered in this flight (Walter, Rhodes, Brown and Adey, 1966).

The basic procedures involve extensive spectral analyses, accomplished by digital computation, with calculation of auto- and cross-spectral densities, including phase angles, shared amplitudes and coherence functions. These techniques, based on digital filtering methods, and endowed with great sensitivity and fine resolution, are amongst the most powerful mathematical tools available for evaluation of linear interrelations in wave-generating systems (Walter, 1963).

Analog signals from the physiological signal conditioners will be sampled at rates from 12.5 per second to 100 per second, depending on the bandwidth of signals involved, and converted to PCM for telemetry. These signals will be acquired by tracking stations in North and South America for some part of each orbit. It is anticipated that, on this basis, approximately 10 minutes data will be acquired every 90 minutes. Additionally, an 8 channel tape recorder will acquire 100 hours of data in the course of the flight on a programmed basis. Data telemetered in the continental U. S. will be retransmitted over microwave links to Goddard Space Flight Center for decommutation and transfer to a conventional digital format on magnetic tape. These tapes will be analyzed in our Data Processing Laboratory, as described above, within a short time of their receipt. It is expected that rapid analyses will keep pace with the course of the flight, meeting requirements for information on current and probably future status of the monkey.

6. Conclusion

This account of the 30-day primate experiment has reviewed the intricate and closely interrelated studies of central nervous, cardiovascular and metabolic functions, which have been painstakingly woven into a single entity.

Manifestly, orientation in space flight requires consideration, not merely of vestibular mechanisms and closely related ocular coordination, but of the whole hierarchy of functions in focusing of attention and visual discrimination. The former constitute the basic platform in a pyramid of increasingly complex central integration. The latter involve the interplay between cortical sensory systems and subcortical structures that are profoundly influenced by limbic activity. Limbic controls, particularly in the hippocampal system, appear essential to the fine focusing of attention necessary for the laying down of memory traces about spatially organized stimuli. Interference with such controls leads to degradation of spatial discriminative abilities in subtle but important ways, having particular relevance to problems of space flight.

It has been our joint purpose to monitor as comprehensively as possible within the frame of a single experiment the gamut of sensory, motor and higher nervous functions that relate to visual coordination, spatial orientation, recent memory and discriminative ability in prolonged space flight. We have been equally mindful of the need to consider the whole animal, insofar as maintenance of central nervous function depends so vitally on cardiovascular and metabolic integrity.

Summary

Central nervous mechanisms underlying orienting and visual discriminative functions are discussed. Interrelations of vestibular and optic sensory influxes with cortico-diencephalic and limbic mechanisms as essential substrates for spatial orientation are reviewed. Techniques for central nervous, cardiovascular, peripheral nervous and autonomic monitoring during the 30-day primate flight in Biosatellite D

are discussed. A 6.8 Kg Macaca nemestrina monkey will be tested in two behavioral tasks involving delayed matching-to-sample, and an eye-hand coordination test. Environmental support involves an oxygen-nitrogen gas system. Pellet feeding combines reward and ad libitum methods, with water provided from the fuel cell power system. Data acquisition and analysis techniques are reviewed.

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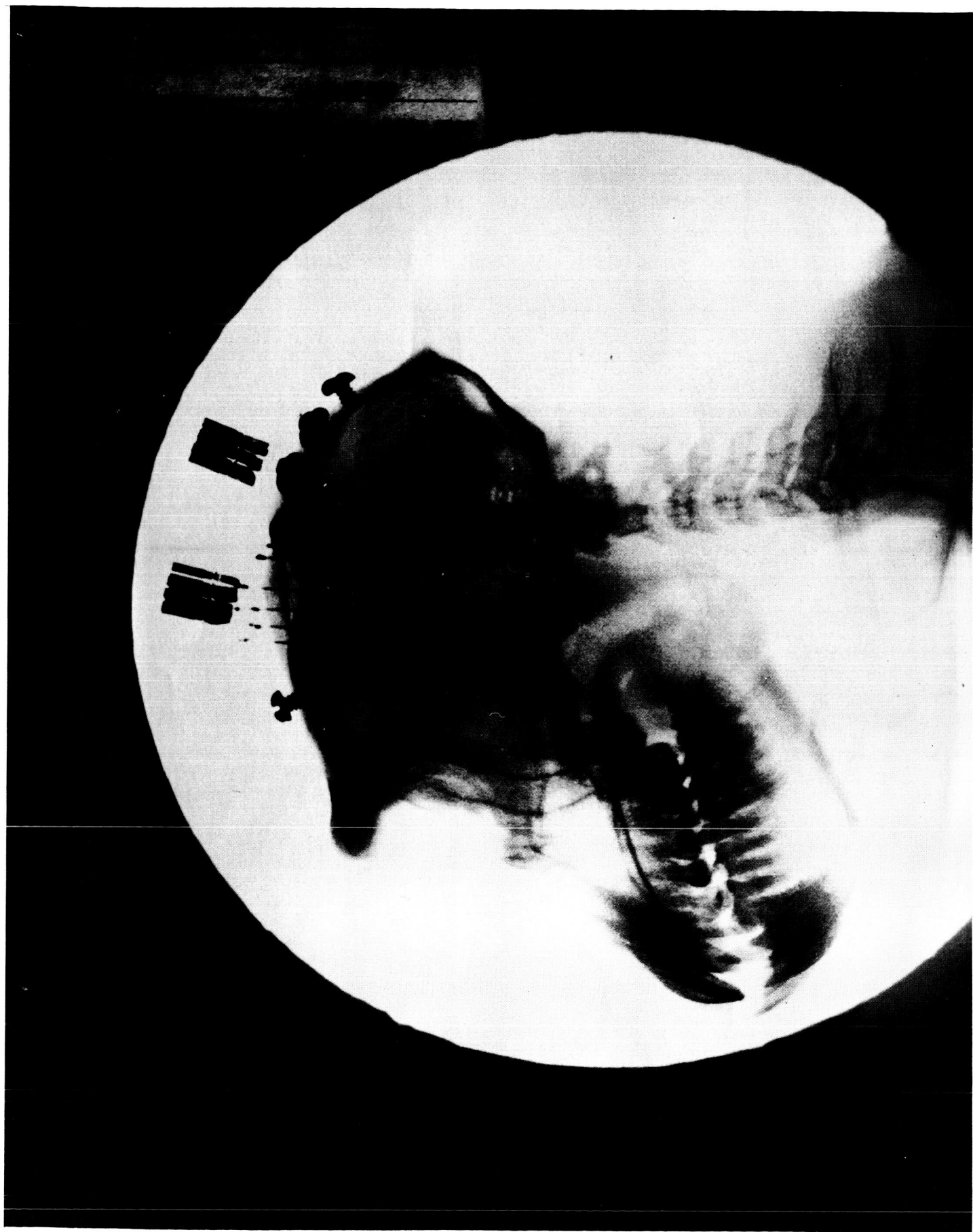
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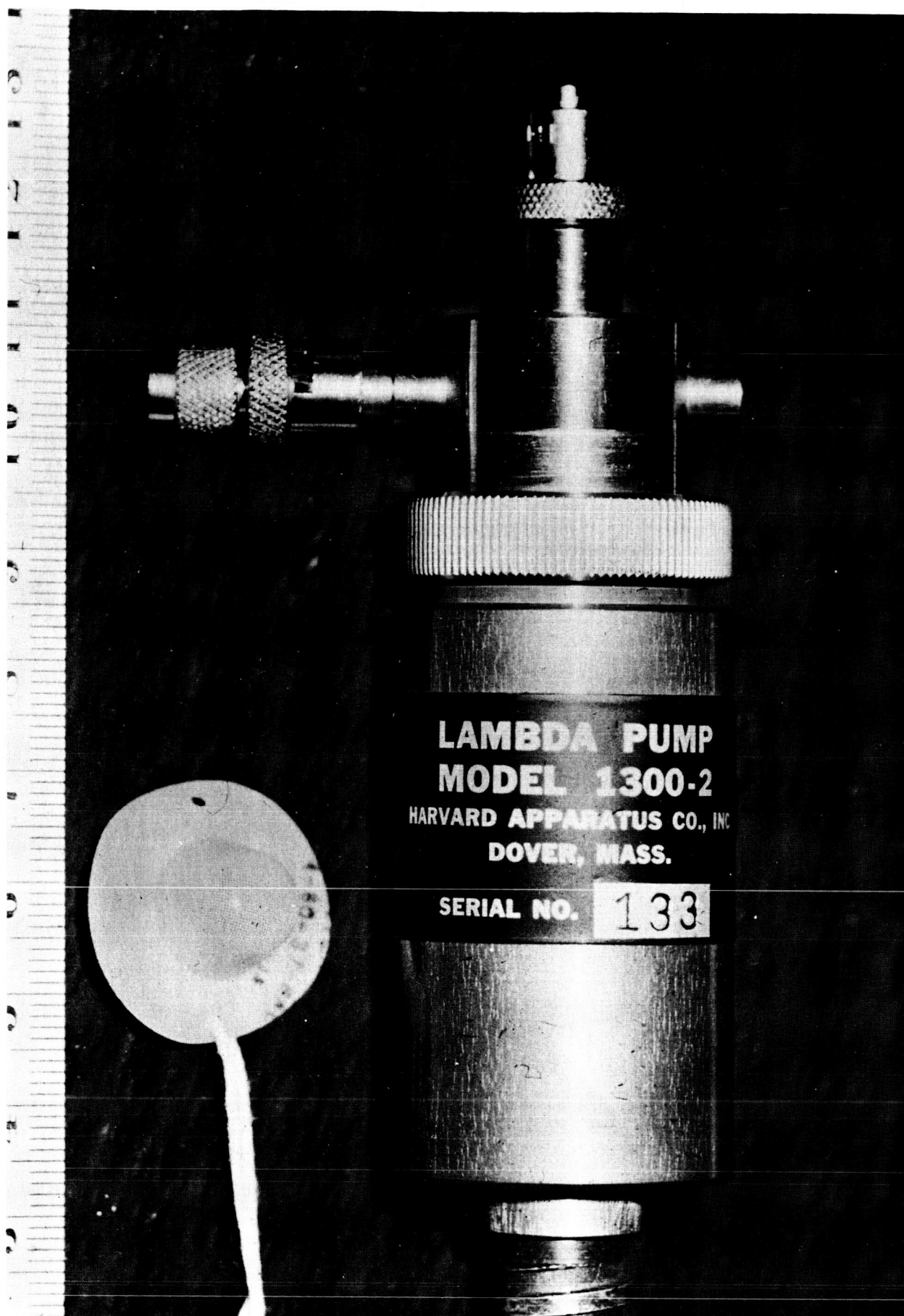
Legends to Figures

- Fig. 1. Xray of head of Macaca nemestrina monkey, showing implanted electrodes of stainless steel tubing (29 gauge) stereotaxically implanted in deep brain structures. Screws in calvarium provide attachment for surface cortical EEG leads, as well as mechanical fixation.
- Fig. 2. Impulse pump for injection of small amounts (0.003 ml) of anti-coagulant solution at one-minute intervals.
- Fig. 3. Arrangement of psychomotor test panel, showing windows for matrix of symbols used in delayed matching-to-sample task. Discs for eye-hand coordination test surround the matrix display.
- Fig. 4. Performance in eye-hand coordination test. Subject must touch button on rear disc through window in front disc. Test monkeys perform at more than 30 per cent correct at disc rotation speeds around 90 r.p.m.
- Fig. 5. Pellet feeder, modified from Holloman AFB chimpanzee feeder. Eight tapes each carry 225 rectangular pellets on adhesive tapes. The pellets are dispensed by traction on the handle and appear in 3 windows successively.
- Fig. 6. Water dispenser, having 30 ml capacity and solenoid controlled. This device requires suction by the animal, and is filled with filtered water from the fuel cell power source.
- Fig. 7. Effects of compound transverse and spin accelerations on EEG during booster profile for attainment of orbital flight (A). Frequency analyses show major changes in energy distribution following high G "pulse" in hippocampus (B), Visual cortex (C) and amygdala (D).
(From Adey, Kado and Walter, 1965)

- Fig. 8. Paroxysms of high amplitude slow waves in cortical and subcortical structures (D) during resting phase after 12G acceleration, showing missed cardiac beats during EEG paroxysms, but not in intervening intervals. Effects of spin and centrifuge on EEG are clearly evident (E). Abbreviations: L. Vis. Cx., left visual cortex; R. AMYG., right amygdala; R. HIPPO., right hippocampus; R. MB. R. F., right midbrain reticular formation; EKG, electrocardiogram. (From Adey, Kado, and Walter, 1965).
- Fig. 9. Models of autospectral contours in normal monkey before and during shaking at decreasing frequencies from 17 to 5 cycles per second. EEG spectrum is depicted on ordinates, vibration spectrum on abscissae, and spectral power on Z-axis (in microvolts squared per cycle per second) for visual cortex (A), amygdala (B), nucleus centrum medianum (C), midbrain reticular formation (D), and head accelerometer (E). (From Adey, Kado and Walter, 1965).
- Fig. 10. Plots of coherence (linear predictability) between centrum medianum and visual cortex (A), vertical head accelerometer (B), and table accelerometer (C) during vibration. Similar plots are shown between visual cortex and midbrain reticular formation (D), head accelerometer (E) and table accelerometer (F). Ordinates show EEG spectrum, abscissae the vibration spectrum and Z-axis the level of coherence. With 12 degrees of freedom, coherence levels were significant above 0.516. Significant coherence levels at the shaking frequency are shown in solid black, and at points away from the shaking frequency in stipple. (From Adey, Kado and Walter, 1965).

- Fig. 11. Plots of coherence as in Fig. 10 between the table accelerometer and visual cortex (A), amygdala (B), centrum medianum (C), midbrain reticular formation (D), and hippocampus (E), after bilateral 8th nerve section. With 24 degrees of freedom, coherence levels were significant above 0.326. (From Adey, Kado and Walter, 1965).
- Fig. 12. Oblique view of biosatellite mockup, showing disposition of animal on restraining couch, with behavioral programmer before him.
- Fig. 13. Frontal view of biosatellite mockup, showing relationship of animal to feeder and water dispenser.

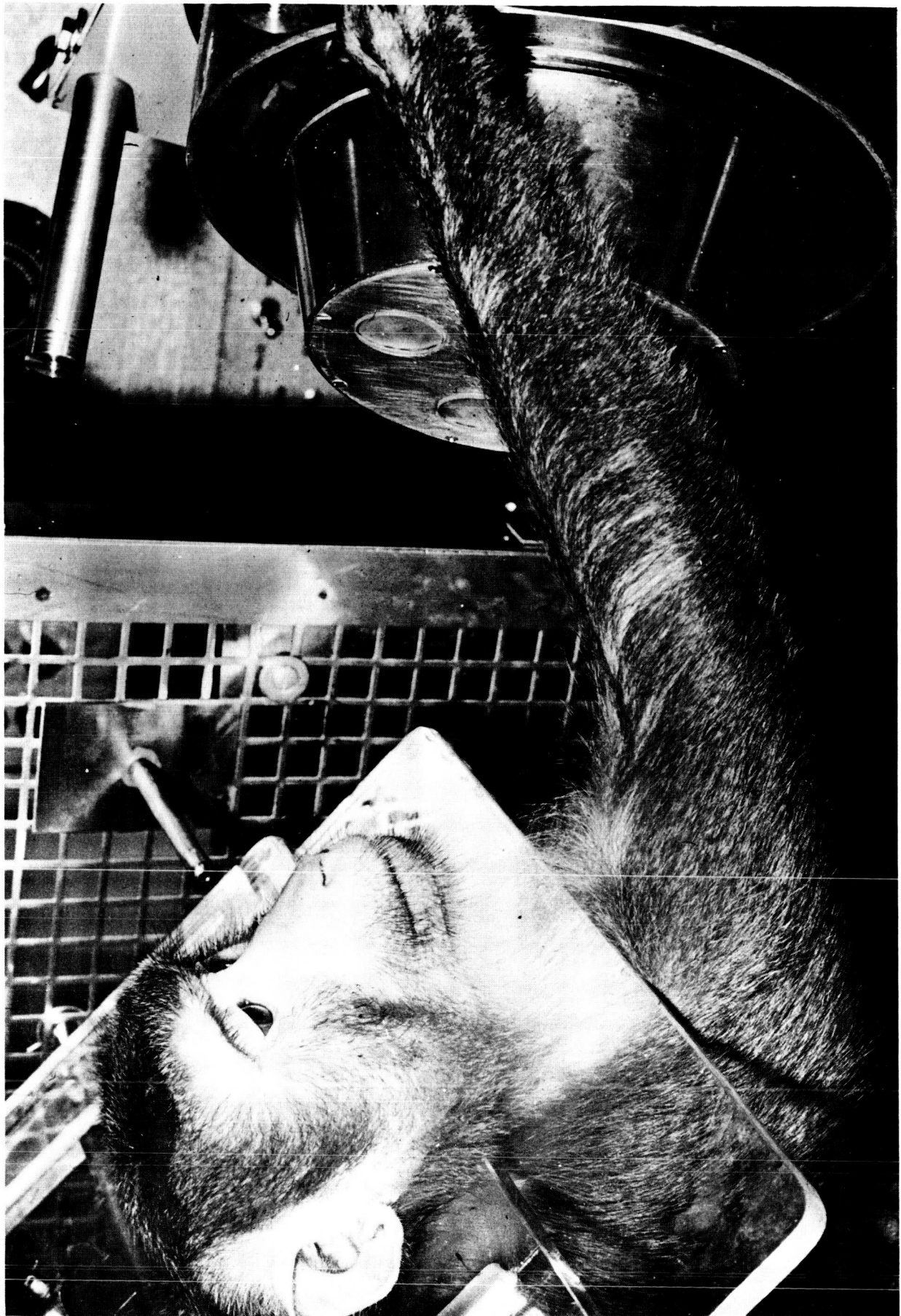


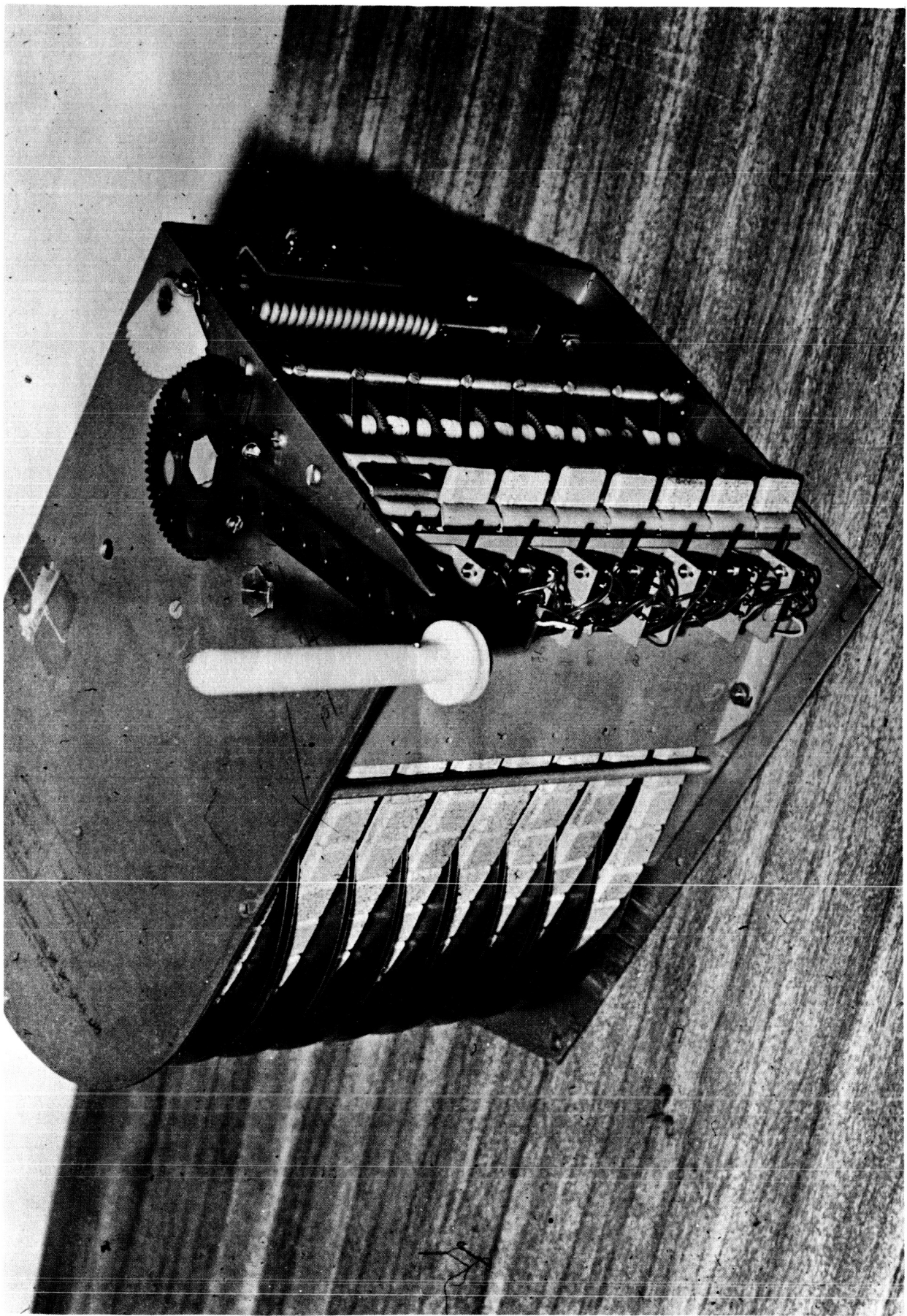


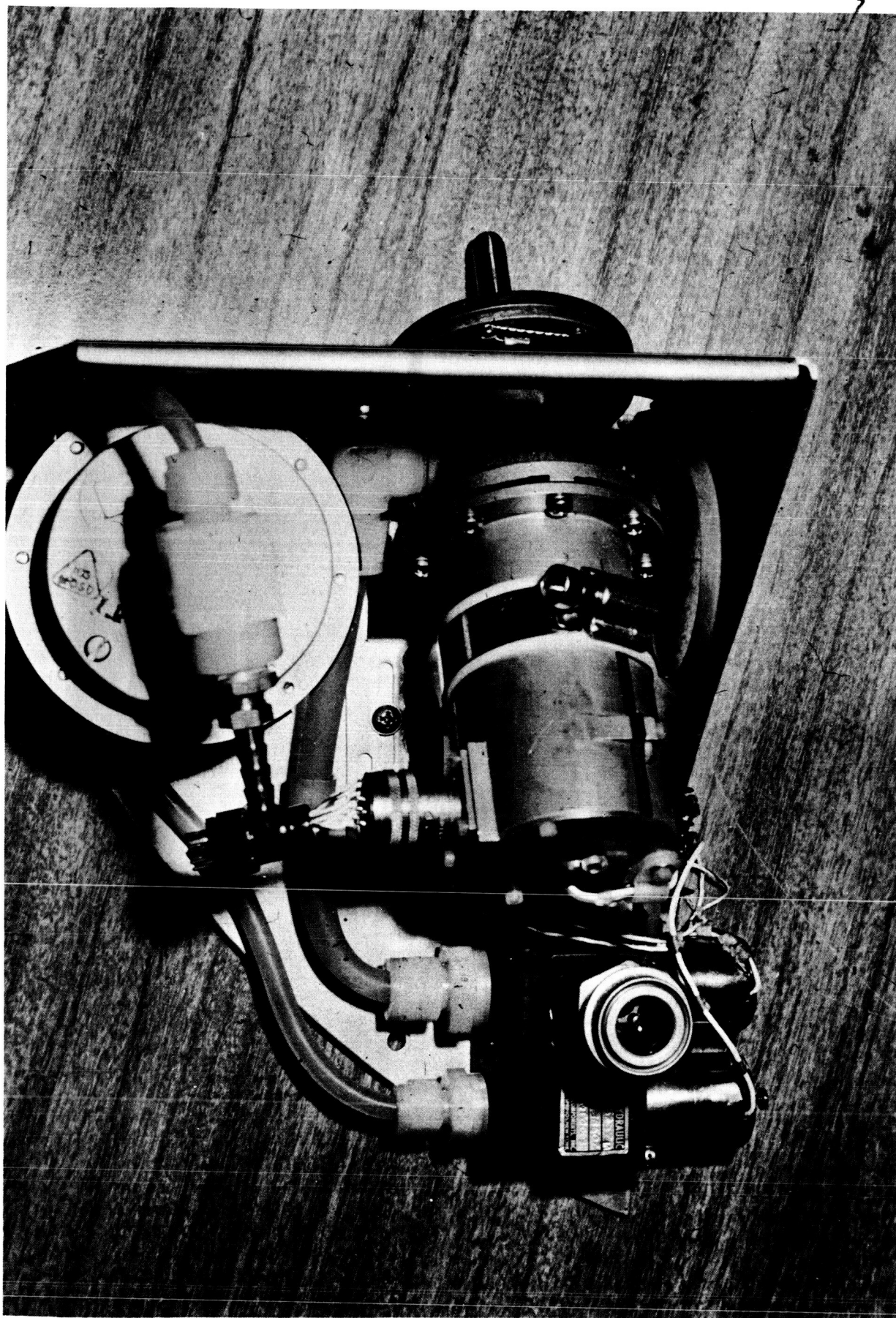
LAMBDA PUMP
MODEL 1300-2
HARVARD APPARATUS CO., INC.
DOVER, MASS.

SERIAL NO. 133



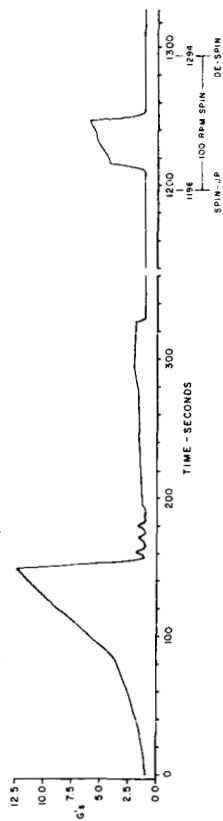






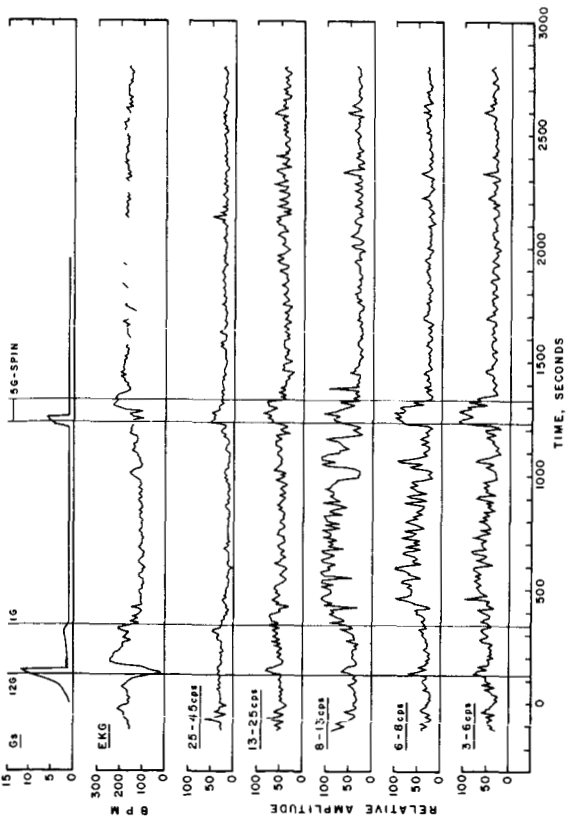
A.

MONKEY CENTRIFUGE-SPIN RUN N6
ACTUAL CENTRIFUGE "G" PROFILE



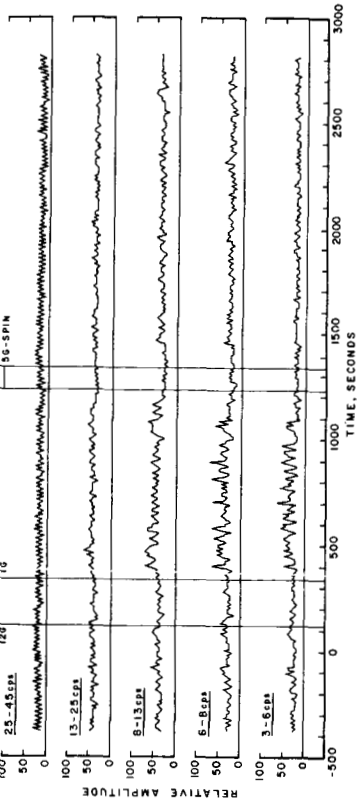
C.

EEG FREQUENCY BANDS L. VIS. CX. MONKEY CENTRIFUGE-SPIN DEC. 1964



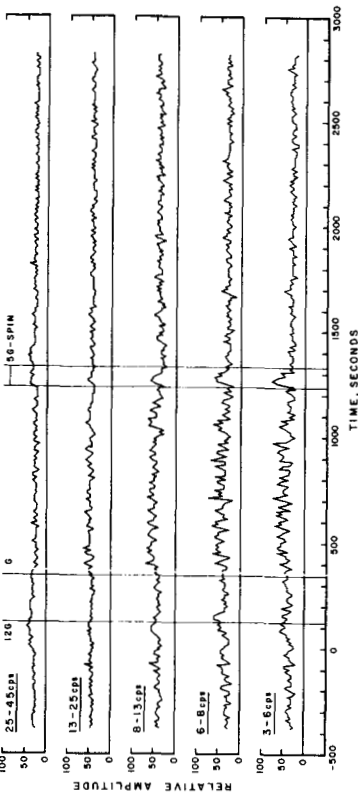
B.

EEG FREQUENCY BANDS R. HIP. MONKEY CENTRIFUGE-SPIN DEC. 1964



D.

EEG FREQUENCY BANDS R. AMYG. MONKEY CENTRIFUGE-SPIN DEC. 1964

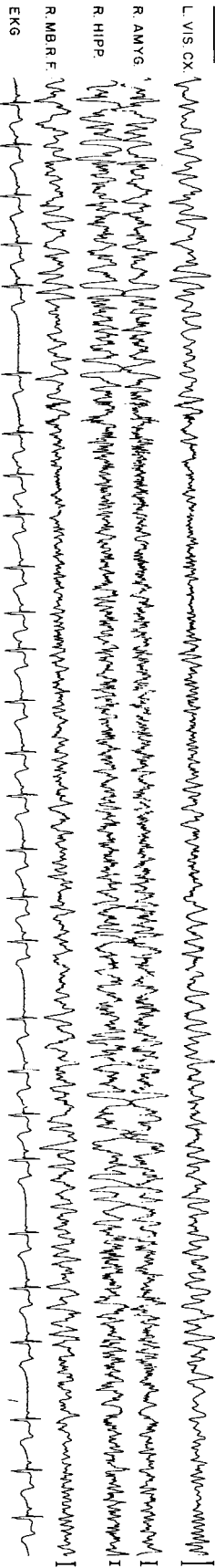


MONKEY CENTRIFUGE-SPIN RUN
 EYEBALLS-OUT CENTRIFUGING, WITH ADDED SPIN ABOUT DORSO-VENTRAL AXIS

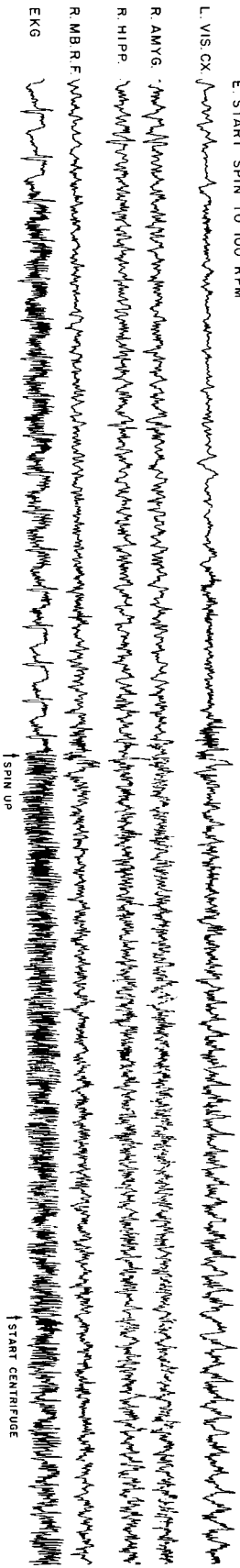
N6 DEC. 1963

PLATE 2: D POST CENTRIFUGE WAIT

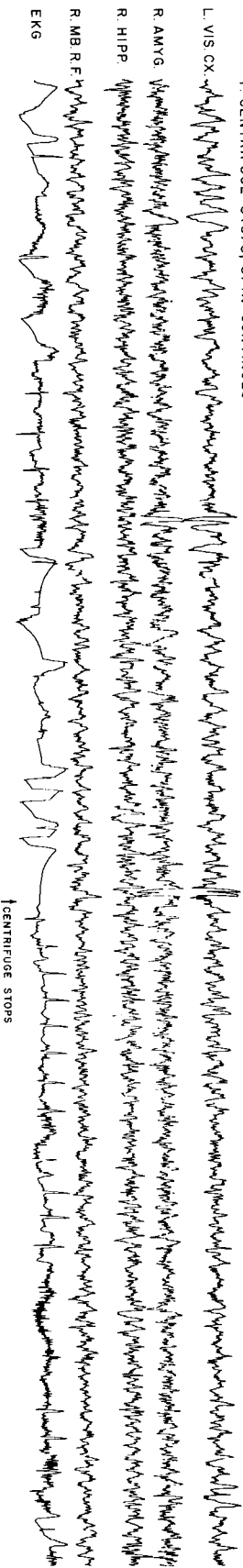
0.5 SEC — 100 μV



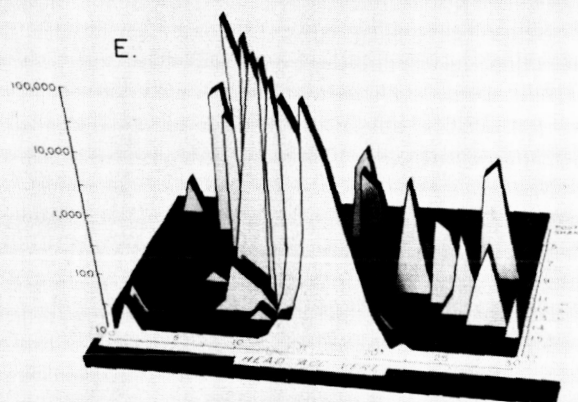
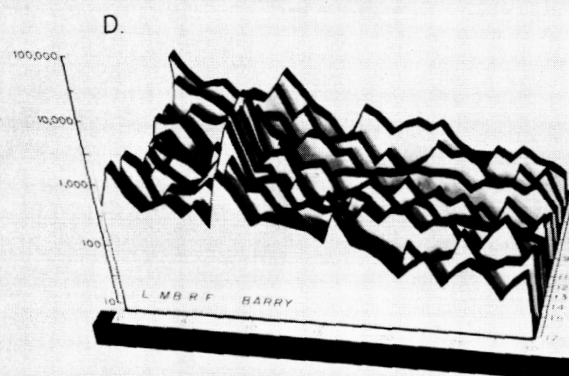
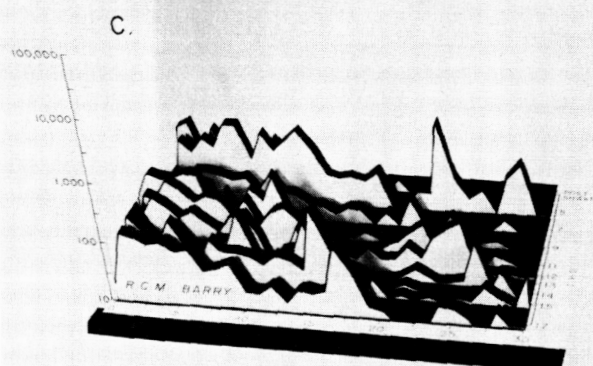
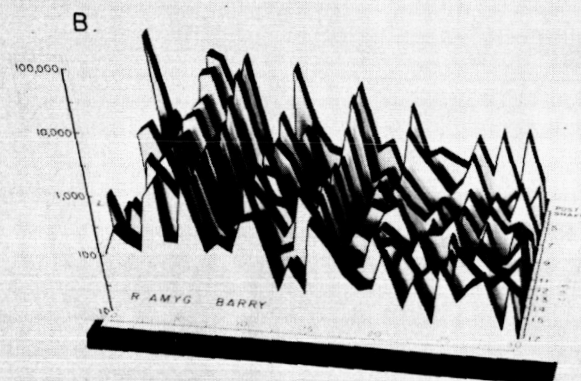
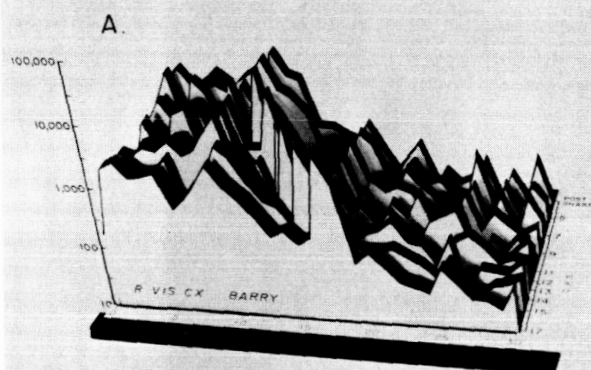
E. START SPIN TO 100 RPM



F. CENTRIFUGE STOPS, SPIN CONTINUES

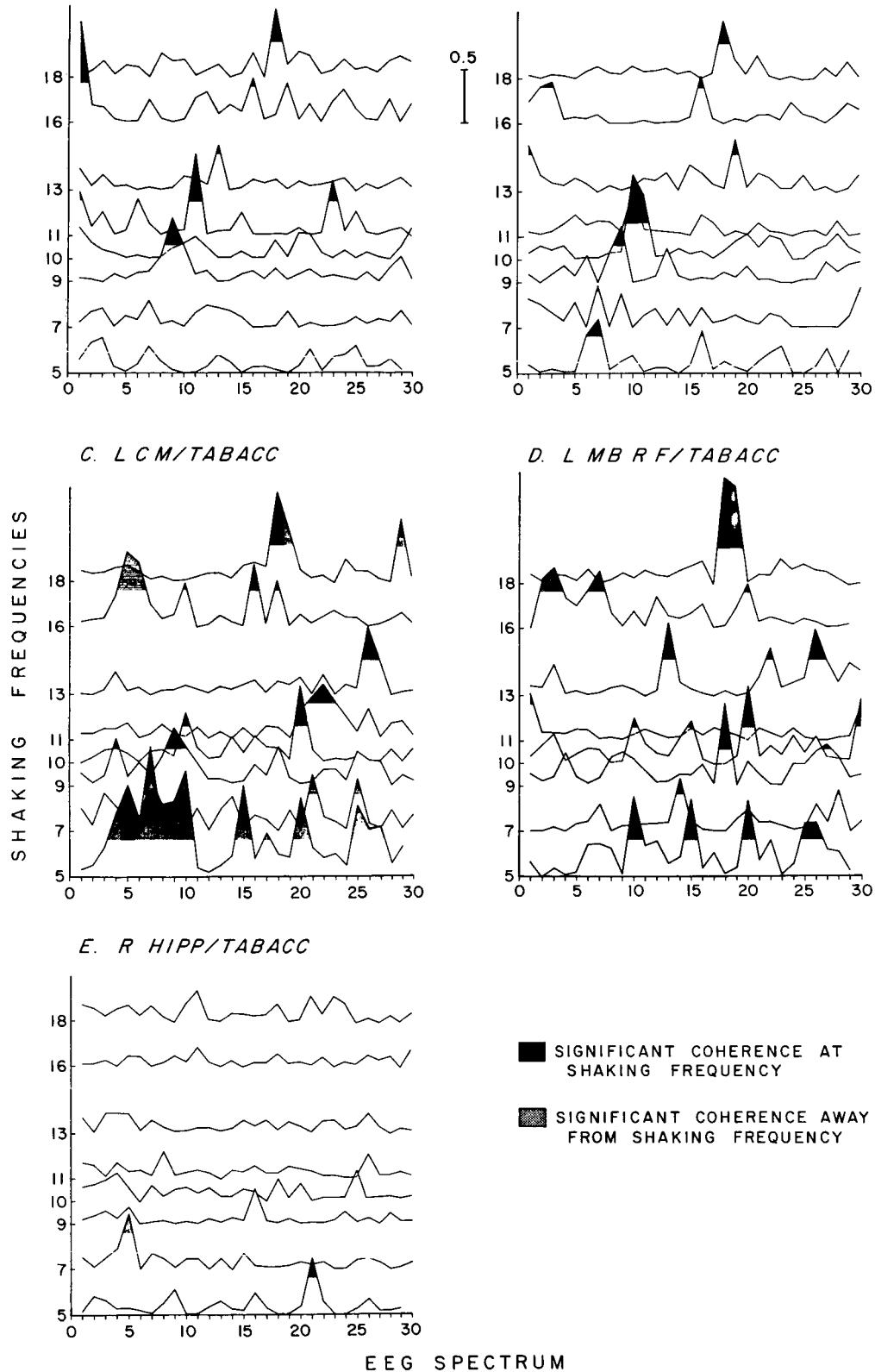


AUTOSPECTRAL CONTOURS DURING VIBRATION NORMAL MONKEY



SIGNIFICANT LEVEL AT 0.326

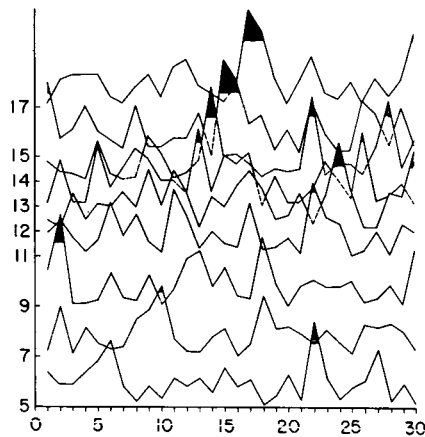
B. R AMYG/TABACC



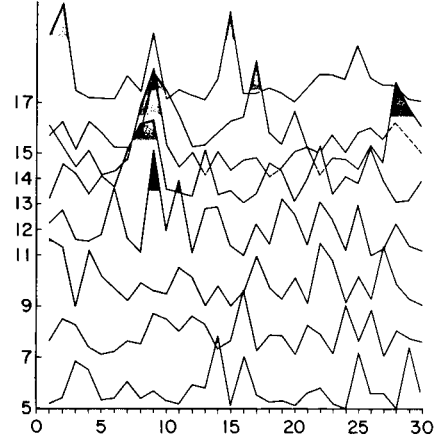
PLOTS OF COHERENCES (LINEAR PREDICTABILITY) DURING VIBRATION - NORMAL MONKEY

SIGNIFICANT LEVEL AT 0.516

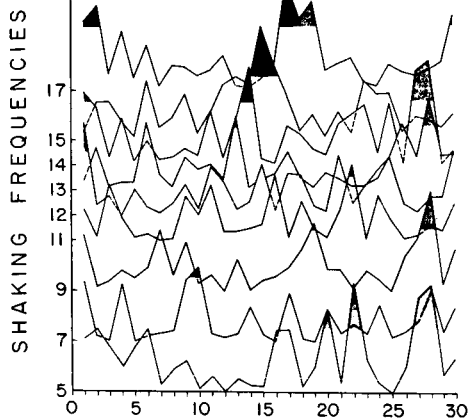
A. R C M / R VIS CX



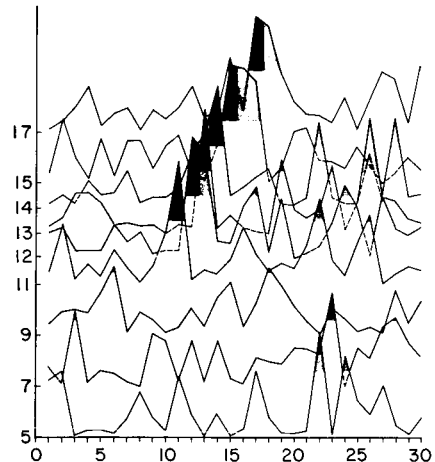
D. R VIS CX / L MB R F



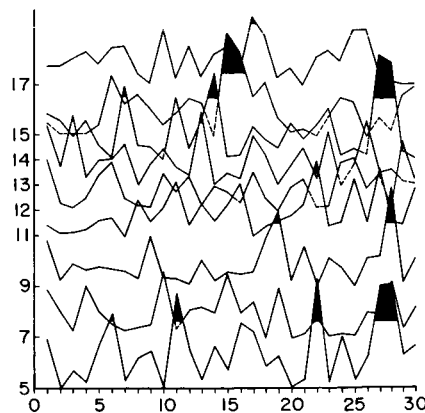
B. R C M / HEAD ACC VT



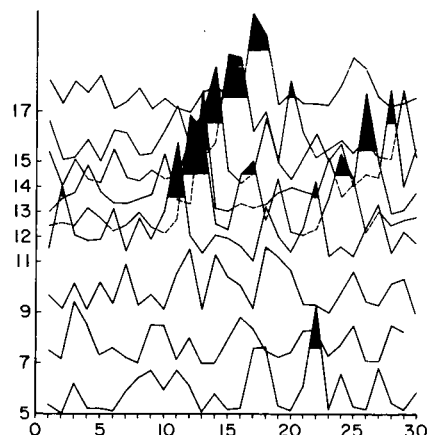
E. R VIS CX / HEAD ACC VT



C. R C M / TABACC



F. R VIS CX / TABACC



EEG SPECTRUM

■ SIGNIFICANT COHERENCE AT SHAKING FREQUENCY

▨ SIGNIFICANT COHERENCE AWAY FROM SHAKING FREQUENCY

